Evidence of a common understanding of proximate and distal drivers of reef health

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Highlights

- Expert perceptions of proximate and distal drivers of Caribbean coral reef health
- Research on distal drivers remains limited compared with proximate drivers
- 173 drivers of reef health identified, including 37 proximate and 136 distal
- Perceptions about fishing and reef management differ by country and sector
- Perceptions-based approaches provide evidence for marine management priorities

Abstract

Marine management has typically prioritised natural science methodological traditions as an evidence base for decision-making; yet better integration of social science methods are increasingly shown to provide a more comprehensive picture to base management decisions. Specifically, perceptions-based assessments are gaining support, as they can provide efficient and holistic evaluation regarding management issues. This study focuses on coral reefs because they are particularly threatened ecosystems, due to their ecological complexity, socio-economic importance, and the range of environmental drivers that impact them. Research has largely concentrated on assessing proximate threats to coral reefs. Less attention has been given to distal drivers, such as socio-economic and governance factors. A common understanding of threats related to coral reef degradation is critical for integrated management that takes account of peoples' concerns. This study compares perceptions of drivers of reef health among stakeholders (n=110) across different sectors and governance levels, in four Caribbean countries. Interview data identified 37 proximate and 136 distal drivers, categorised into 27 themes. Five sub-groups of themes connecting proximate and distal drivers were identified. Perceptions of two of these narratives, relating to 'fishing and socioeconomic issues' and 'reef management and coastal development', differed among respondents from different countries and sectors respectively. However, the findings highlight a shared perception of many themes, with 18 of the 27 (67%) mentioned by >25% of respondents. This paper highlights the application of perceptions data for marine management, demonstrating how knowledge of proximate and distal drivers can be applied to identify important issues at different context-specific scales.

1. Introduction

The effectiveness of natural resource management is a continuing global concern, and is hindered by incomplete knowledge and understanding of complex social-ecological systems [1], leading to a limited appreciation of the impacts of social, economic, political and environmental change on natural resources exposed to threats such as climate change [2]. This complexity presents natural resource managers with the challenge of prioritising and addressing a multitude of threats to natural resources, often with limited financial resources [3, 4]. Prioritisation of research and management strategies for natural resources rely on the perceptions and knowledge of managers, policy makers and scientists, their ability to share understanding, and to develop common goals and research priorities. While scientific knowledge and evidence-based management are typically given precedence as a basis for resource management decisions, priority- and agenda-setting [5-7], there are compelling reasons to understand how individuals involved in the management of natural resources perceive environmental threats.

Several studies have highlighted the benefits of collaborative priority-setting exercises with various actor groups (policy makers, managers and scientists) involved in conservation science and natural resource management [8-10]. Priority-setting exercises to identify and prioritise research questions have been undertaken across a range of scales and contexts, including for specific resource sectors such as agriculture, fisheries and marine conservation [11-14]. However, few studies have applied participatory methods to collate perceptions regarding environmental threats, specifically in relation to globally declining marine ecosystems, for example coral reefs [4, 15-17]. Gathering opinions with the aim of developing a common understanding and building consensus regarding environmental issues can facilitate shared understanding in natural resource management [1, 18, 19]. For example, it has been suggested that informing policy with a shared understanding of key individuals' perceptions about threats may help reduce the uncertainty and competing knowledge and priorities that currently beset coral reef management [20]. Furthermore, as the underlying foundation of beliefs and perceptions of individuals are known to influence and determine behaviour [21], awareness of perceptions is key when implementing effective management.

Coral reefs are an ideal case study to explore these issues, because many are impacted locally and to varying degrees by several key drivers (i.e. fishing, pollution, development), yet also all face significant pressure from climate change impacts [22]. It is widely acknowledged that coral reefs are some of the most complex, and heavily threatened marine ecosystems worldwide, that they continue to deteriorate as a result of human activities [23-25] and governments urgently need to prioritise effective management measures to address this negative trend. More than 60% of reefs are estimated to be under immediate and direct threat from local stressors such as overfishing, coastal development, and physical damage [26, 27]. In conjunction with climatic changes, this figure rises to 75% [27]. Caribbean coral reefs are particularly at risk [28], experiencing rapid ecological decline [29]. Growing demands for coral reef-related ecosystem services, from fisheries, dive tourism and shoreline protection, together with predicted impacts from climate change, make improving Caribbean coral reef management a necessity [27, 30, 31].

As the intensity of stressors affecting coral reefs is expected to increase, managing and discriminating among threats will be critical to support conservation efforts [24]. Several reviews highlight a broad suite of proximate and distal threats affecting coral reefs globally [23, 32, 33]. Proximate drivers are those acting directly on the reef to produce a negative impact on its health, for example coral bleaching [e.g. 34], increasing algal cover [35], removal of herbivores [36] and coral disease [23].

Distal drivers are those that are physically removed from the reef, but underlie proximate impacts; such as, climate change [37, 38], poverty [10], and poor governance [30, 39].

Understanding the implications of all drivers of reef degradation is of both scientific interest and practical relevance for coral reef management [31]. However, research on distal drivers remains limited in comparison to the range of studies assessing proximate drivers of coral reef degradation [2, 16, 40, 41], particularly when the regional Caribbean picture is considered [28, 42, 43]. While many coral reef management interventions are based on sound scientific knowledge, it is argued that they often fail due to a poor understanding of the underlying social, economic and governance contexts [40, 44]. There is a pressing need to re-focus research on the role of distal drivers of coral reef decline to understand the diverse human dimensions of coral reefs [2]. This is critical to ensure the continued flow of coral reef ecosystem services in this period of rapid environmental change [30, 33, 45].

This research addresses a knowledge gap in coral reef management by specifically focusing on an assessment of perceived proximate and distal threats to Caribbean reefs among individuals involved in coral reef management, including managers, policy-makers and scientists. The Caribbean is an ideal case study because the coral reefs in the region have been highlighted as particularly threatened by a range of common stressors [e.g. 27, 28, 46], and it is geographically, socio-economically and politically diverse, which may influence perceptions of threats. There has not yet been a systematic assessment of perceived threats to Caribbean coral reefs that includes the broadest suite of both proximate and distal drivers.

This study demonstrates the importance of understanding perceptions of threats among individuals responsible for reef management across different countries, employed in a range of reef-related sectors (e.g. fisheries, environment, tourism, and conservation), and working at different governance levels (local and national). The coral reefs of the four study countries (Barbados, Belize, Honduras and St Kitts and Nevis) all face common anthropogenic threats, for example from fishing, coastal development, pollution and climate change [27]. However, each country's reefs have experienced a different history of natural disturbance and varying levels of marine protection, [e.g. see 47, 48-50], leading to country-specific differences in the status of reef health [51]. This study therefore hypothesised that perceptions would differ among countries. For example, actors in the Central American countries (Belize and Honduras) with a long and extensive history of marine protection, might be expected to have different perceptions regarding reef health and management compared to the island countries (Barbados and St Kitts and Nevis). Similarly, there was an expectation that divergences in perceptions between different sectors and governance levels, as expertise in different areas or at different jurisdictional scales, will focus attention and develop a knowledgebase around specific threats. The objectives of this study were therefore to: 1) identify both the proximate and distal drivers of coral reef health perceived by individuals involved in coral reef research and management in the four Caribbean countries; and 2) to explore differences in perceptions of these drivers among countries, sectors and governance levels.

2. Methods

2.1. Study sites

Data were collected in Barbados, Belize, Honduras, and St Kitts and Nevis, selected to represent a range of coral reef health, social and economic conditions, governance and management structure, and

levels of marine resource dependency across the region (Table 1). Coral reefs are important for small-scale fisheries and coastal tourism in all four countries, providing employment, income and food security; although levels of dependence differ among countries (Table 1).

Table 1. Characteristics of study countries (country statistics source: [51]; *[50]; **[52] ***Data do not distinguish between coral reef fisheries from other forms of fishing practices [53]; #Data denote contribution of fisheries and aquaculture [54]).

Country statistics	Barbados	St Kitts and Nevis	Belize	Honduras
Land area (km^2)	430	168	22,966	112,088
Continental or island	Island	Island	Continental	Continental
Shelf area to 30m within Maritime Claim (km^2)*	80	460	7850	35850
Caribbean coastline length (km)*	95	120	2220	2325
Land area draining to Caribbean (km^2)*	430	270	22965	92395
Population (2008)	255,203	51,065	300,647	7,318,789
Population change 1990-2000 (% change)*	4.0	-8.1	21.9	31.8
Population density 2000 (people/km^2)*	622	143	10	57
GDP per capita (US$) (2008)	14,422	10,874	4,569	1,957
GDP % contribution fisheries***	0.9	1.42	7.2	5.25#
GDP % contribution tourism	11.8	6.9	23.2	Unavailable
Reef area (km^2)*	90	160	1420	1120
% of reefs facing high or very high threats*	100	100	34	21
% at med/high risk from coastal development*	100	95	11	25
% at med/high risk from land-based sediment and pollution*	60	100	49	10
% at med/high risk from marine-based pollution*	15	26	8	6
% at med/high risk from fishing pressure*	100	100	37	29
Number of MPAs**	1	0	19	18
Total MPA area (km^2)**	2.1	0	2554	2167

As reef management takes place at both national and local levels within each country, three sites were chosen for study at the local level (Fig. 1. b-e). Site selection sought to capture a gradient of reef resource use, selecting one site where reef use is predominantly by reef fisheries, one where reef-related tourism is predominant, and one where a mixture of reef-related tourism and fishing was present.

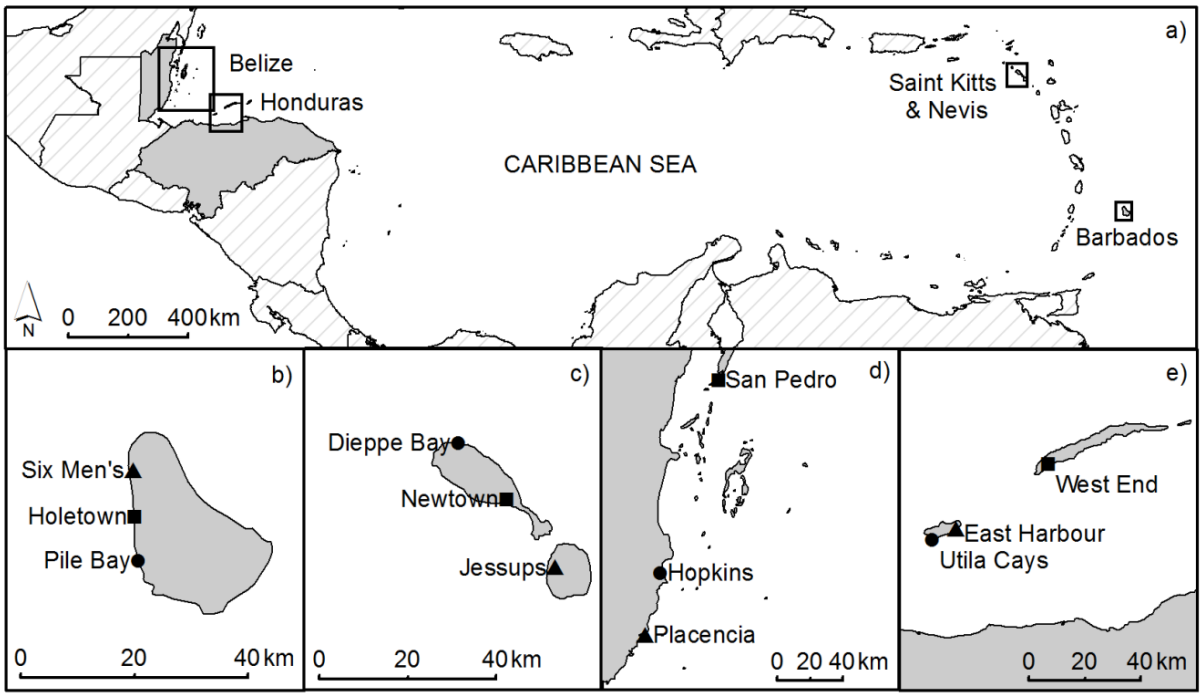

Figure 1. Maps of a) location of study countries, and (b-e) study sites within Barbados, St Kitts and Nevis, Belize and Honduras. Symbols represent reef-use characteristics of each community; circle = predominantly fishing, triangle = mixed fishing and tourism, square = predominantly tourism [Source: 55].

2.2. Data collection

Semi-structured interviews were carried out in each country at local (*n*=49) and national (*n*=61) levels, enabling collection of rich and detailed data of perceptions of current drivers of reef health at different scales. Local level respondents included individuals involved in reef management or decision-making within the twelve communities (Fig. 1. b-e). National level respondents included individuals involved in reef management, decision-making or policy at a national level.

Interviews were conducted between February 2011 and August 2012. Lists of potential respondents in each country were derived from preliminary internet searches and grey literature (e.g. documents and reports by local organisations), and validated during initial interviews. Snowball sampling was used to further populate the list of respondents to interview. Respondents were targeted purposively to be representative of the range of actors involved in reef management in each country. A broad range of individuals representing a variety of sectors and organisations at different levels participated in the study (Table 2). Sectors included reef resource use (fisheries and tourism), and those relating to the community, enforcement, conservation, environment, and research. Sectors spanned government departments or ministries with a responsibility for reef management or resource use, non-governmental organisations involved in reef management, research and stakeholder support, industry organisations with interests in reef or marine resources, and educational organisations such as universities undertaking research on coral reefs.

Table 2. Number of respondents interviewed from each country, at each governance level and within the seven sector types.

Country		Barbados	St Kitts and Nevis	Honduras	Belize	Total
Level	Local	5	1	20	23	49
	National	9	24	13	15	61
Total		14	25	33	38	110
Sector	Community	0	0	1	2	3
	Conservation	3	4	12	15	34
	Enforcement	1	2	6	2	11
	Environment	2	5	7	3	17
	Fisheries	3	8	5	5	21
	Research	2	2	0	1	5
	Tourism	3	4	2	10	19
Total		14	25	33	38	110

Interviews lasted between 45-90 minutes. Interviews were audio recorded and then transcribed verbatim, unless participants were unwilling, in which case detailed notes were taken. The semi-structured interviews included questions regarding: the respondent's sector; perceptions of reef health and impacts to reefs; and reef management and governance. Open-ended questions were specifically asked to elicit perceptions of proximate and distal drivers of reef health, (i.e. '*What do you think are the most important impacts to reefs in your area/country?'* and *'What are the causes of these impacts?'*). These two key questions were intentionally designed to elicit responses about proximate and distal drivers, but without leading the respondents to think in either terms, thereby allowing respondents to divulge the full list of impacts they could think of, and the associated underlying causes of each impact. Respondents were therefore encouraged to describe the combinations of distal factors that led to proximate stressors, and were not constrained to single answers in relation to any threat. Many respondents also made references to proximate and distal drivers in response to other questions about reef health and management throughout the interviews, which were also included in the analysis. As the interviews were intended to collect a wide range of information on reef governance and management in addition to drivers of reef health, respondents were asked additional questions relating to governance and management drivers.

2.3. Data analysis

Interview transcripts were coded using NVivo 9 [57], by two researchers, with frequent cross-checks and discussion with the wider research team. The coding structure was developed iteratively. The first phase used inductive coding to identify all different drivers mentioned. Each statement in the transcripts that revealed a perceived relationship between a proximate driver and reef health (e.g. *"sediment affects the reefs"*), between an distal driver and a proximate driver (e.g. *"poor agricultural practices lead to sedimentation"*), or between two distal drivers (e.g. *"lack of awareness leads to poor agricultural practices"*) was coded. This resulted in an extensive and diverse set of drivers, and initiated the second coding phase, which used a more deductive approach, based on a review of threats described in the scientific literature, to group the drivers into related themes (Table 3). For example, the 'coastal habitat destruction' theme comprised any drivers that mentioned issues relating to the direct loss of wetland, mangrove or seagrass habitats, or sand mining. Given the focus of the interview questions on coral reefs, statements inferring impacts on coral reef health without explicitly

mentioning reefs, for example *"Poor agricultural practices lead to sedimentation"*, were also coded as a relationship between sedimentation and reef health. An NVivo coding matrix query displayed the number of respondents that mentioned each theme across the four countries, two governance levels and seven sectors.

Principal Components Analysis (PCA) was used to identify subsets of related driver themes that were correlated with one another but independent from other drivers, reflecting underlying narratives connecting drivers themes [16, 58]. Three themes were not included in the PCA. First, 'governance structure and process' was removed on account of it being mentioned by 100% of respondents, and therefore not varying across the sample. In addition, this theme was a specific focus of prompting in the wider interview, resulting in a large number of drivers (59) which is beyond the scope of this paper to fully explore. Second, 'other ecological changes' and third, 'social drivers' were excluded because drivers within these were mentioned infrequently and were not strongly associated with any theme. In total 24 driver themes were included in the PCA, which was based on a correlation matrix and used varimax rotation of the principal components (PCs) to help interpret indicator loadings and identify underlying narratives. Classification trees were used for each PC retained to identify how perceptions of these narratives varied among respondents. Respondent-level PC scores were included as the dependent variable, and the nominal variables site, governance level and sector as predictors. Statistics were conducted with the psych and rpart packages in R [59].

3. Results

3.1. Proximate and distal driver coding framework

In total, 173 drivers of reef health were identified, including 37 proximate and 136 distal. These were categorised into 27 themes (11 proximate and 16 distal) (Table 3). Proximate driver themes included those related to ecological issues affecting reefs, habitat, resource use, and direct climatic impacts. Distal driver themes included coral reef governance and management, social and economic issues and other external influencing factors, as well as physical environmental changes for example from agriculture, climate change and coastal development (Table 3).

The themes each included between 1 to 59 drivers (mean ± SD = 6.4 ± 11.5 drivers per theme). The number of drivers associated with each theme provides an indication of dimensionality within each theme, and potentially a level of awareness by respondents. For example, within the proximate driver theme categories, respondents identified only one driver associated with the algae and coral disease themes. However, six drivers were associated with the proximate fishing impacts and pollution themes. Similarly, in the distal driver theme categories, while a few themes contained only one or two drivers (e.g. markets, tradition and culture, non-local impacts), the majority contained numerous different yet thematically associated drivers.

Table 3. The 27 driver themes with the description and number of different drivers included within each theme. The three themes in grey are not included in the PCA.

Driver theme	Description of drivers	Number of drivers
PROXIMATE		
Algae	References to algae growing on, or covering coral reefs	1
Bleaching, water temperature & acidification	Coral bleaching, including descriptions of corals turning white, and references relating to increasing water temperature, and references to ocean acidification	3
Coastal habitat destruction	Drivers relating to loss of mangrove, wetland and seagrass habitats, and sand mining	3
Coral disease	References to coral disease	1
Fishing impacts (direct)	General and specific issues relating to unsustainable fishing, including fishing in protected areas or out of season, fishing undersized, bycatch, discarded gear and fewer herbivores	6
Invasive species	General issues relating to invasive species on reefs, and specific issues relating to lionfish	2
Other ecological changes	A broad array of other ecological drivers mentioned infrequently, including fish migration, red tides, fish kills and *Diadema* die-off	4
Physical damage	General and specific issues relating to physical damage, including boat and anchor impacts, extraction of corals, and diver and snorkeler impacts	3
Pollution	General and specific mention of pollution, including chemical and organic waste, rubbish and sewage, oil and gasoline and sun cream	6
Sedimentation & dredging	References to sedimentation, dredging and erosion affecting corals	3
Storms & natural disasters	Drivers relating to rough seas and hurricanes, earthquakes, sea level rise and high tides, as well as general mention of natural disasters	5
TOTAL PROXIMATE DRIVERS		**37**
DISTAL		
Agricultural changes	Range of drivers relating to agricultural impacts, including shrimp farms, changes in agricultural practices, overgrazing and vegetation removal	6
Climate changes	References to climate change and global warming, carbon emissions, changes in seasonality, rainfall, flooding, and El Niño and La Niña events	6
Coastal development & changes	General issues relating to poor coastal development, as well as drivers relating to quarrying, removal of coastal vegetation and poor drainage	5
Enforcement	Issues of lack of effective enforcement, non-compliance with rules and regulations, and inadequate penalties for infractions	3
Fishing impacts (indirect)	Indirect impacts relating to unsustainable fishing, including increased fishing pressure, technological changes and displacement of fishing effort	5
Governance structure & process	Drivers relating to structures or arrangements in place for reef governance, for example institutional arrangements, legislation and policy. Drivers relating to processes and principles guiding interactions and decision-making, for example leadership and engagement [see 55 for detail of governance processes]	59
Marine transport & industry	Issues relating to shipping and increases in boat traffic, factories and industrial sites	4
Management	Drivers relating to the implementation of reef management measures, for example a lack of marine protected areas, seasonal closures, and alternatives for resource-users; and issues relating to inadequate sewage treatment, watershed management and rubbish disposal. Also includes drivers relating to a lack of specific management plans, and a reliance on ad hoc management for reefs	13
Markets	Issues relating to market demand for coral reef resources	1
Non-local impacts	Reference to general impacts from non-local sources, and specific issues such as pollution	2
Prioritisation	Drivers highlighting a lack of prioritisation or differences in priorities for reef management, or value systems affecting decision-making	3
Resources, capacity & funding	Drivers relating to either a lack of, or an ineffective use of, resources and capacity for management of reefs; as well as issues such as changes to the funding landscape.	4
Social drivers	Social drivers influencing reef management, including political differences, changes in lifestyle affecting people's behaviour and the dynamics of small societies	4
Socioeconomic issues	General and specific mention of socioeconomic issues, relating to livelihood dependency and access to resources, poverty, education, unemployment, population increase and health	15
Tourism	Drivers relating to tourism, including snorkelling and diving impacts, issues of irresponsible tour guiding, cruise ships, and the curio and aquarium trade	5
Tradition & culture	Issues relating to cultural factors, local customs and traditions impacting reef health and management	1
TOTAL DISTAL DRIVERS		**136**

3.2. Patterns in perceived proximate and distal drivers of Caribbean reef health

Respondents' perceptions highlight a shared understanding of many impacts, with 18 of the 27 themes (67%) mentioned by over 25% of respondents (Table 4). Many proximate driver themes were commonly mentioned, with 84% of respondents mentioning pollution, 78% mentioning direct fishing impacts, 76% mentioning physical damage, and 72% mentioning issues of bleaching, water temperature and acidification. Other direct impacts commonly referred to were destruction of reefs from sedimentation and dredging (61%), and damage due to storms and natural disasters (48%). Algae affecting reefs was stated by approximately a third of respondents (31%). In contrast, less than a quarter of respondents mentioned proximate drivers relating to coastal habitat destruction (21%), invasive species (20%) and coral disease (12%).

All respondents mentioned issues relating to governance structure and process (100%), and the majority referred to problems associated with enforcement (96%). Other commonly stated distal driver themes included resources, capacity and funding (89%), management issues (82%), and prioritisation of coral reefs (80%). Respondents' commonly perceived distal threats posed by coastal development (76%), leading to coral reef degradation, and climate change (71%). While the tourism industry and socioeconomic issues were indicated relatively often (63% and 62%, respectively), other social issues, such as indirect fishing impacts (22%), tradition and culture (22%) and markets (11%) were less frequently perceived.

3.3. Differences in perceptions of themes

Country, sectoral and governance level differences in respondents' perceptions of the 27 themes were apparent (Table 4). For example, respondents from Barbados were more likely to perceive proximate drivers relating to pollution (100%), but least likely to mention either of the fishing-related themes (43% (direct) and 0% (indirect)). In contrast, respondents from the other three countries were near-ubiquitous in their perceptions of direct fishing impacts (St Kitts and Nevis (96%), Belize (92%), and Honduras (82%)). Respondents from Belize and Honduras were more likely to mention themes relating to coastal and habitat destruction (32% and 30% respectively), whereas fewer highlighted this in St Kitts and Nevis (20%).

With regards to country level perceptions of distal drivers, there were clear similarities in perceptions of governance structure and process (100%) and enforcement issues (>93%). Some key differences included, Belizean and Honduran respondents more commonly mentioning tourism (79% and 76% respectively) and non-local impacts (50% and 33% respectively). Respondents from Barbados more commonly stated a lack of prioritisation of reef management (93%), impacts from agricultural changes (50%) and local tradition and cultural factors impacting proximate drivers of reef health (43%).

In terms of sectoral differences, the enforcement sector was comparatively more concerned with pollution (91%), and had a relatively low perception of the bleaching, water temperature and acidification theme (55%) and natural disasters (27%); while the fisheries sector more commonly mentioned physical damage causing impacts to reefs (95%). Both of these sectors also had the highest proportion of respondents concerned with indirect fishing impacts on reefs (45%). Perceptions about tourism and non-local impacts were highest among the tourism sector (89% and 58%, respectively). The community sector was found to have relatively high perceptions relating to issues of resources and capacity, prioritisation of reef management, and socioeconomic issues (all 100%); and the

research sector commonly mentioned prioritisation of reef management (100%), and local traditions and culture (50%).

The two governance levels (local and national) were relatively closely aligned in their responses (Table 4). National level respondents were slightly more likely than local level respondents to mention issues relating to bleaching, water temperature and acidification (national, 77% and local, 65%), and coastal development (national, 80% and local, 65%).

3.4. Underlying narratives connecting driver themes

Respondents' perceptions were described by five principal components, which together represented 43% of the variance in the data (Table 5). The first narrative (PC1) was strongly driven by themes relating to coral reef management and impacts from coastal development. The second narrative (PC2) comprised themes broadly relating to fishing and socioeconomic factors. The third narrative (PC3) was driven primarily by themes relating to climate change impacts, pollution, and agriculture. Themes in the fourth narrative (PC4) related to physical damage, storms and natural disasters. The fifth narrative (PC5) primarily reflected a dichotomy between tourism and other external (non-local) impacts, and issues relating to prioritisation of reef management. All five factors included both proximate and distal themes.

Classification tree analysis identified the variables country and sector as best able to predict responses in relation to two of the five narratives (Fig. 2). The variable sector had the greatest power to predict scores on PC1 (reef management and coastal development), distinguishing between stronger perceptions of this narrative among members of the community, conservation and environment sectors, compared with other four sectors. The variable country was best able to predict scores on PC2 (fishing and socioeconomic issues), distinguishing responses among Barbados respondents compared to respondents from the other countries. The governance level variable was not a strong predictor of scores for any of the components. Scores for PC3, PC4 and PC5 were not predicted by any of the respondent characteristics.

Table 4. The 27 driver themes and the percentage of respondents from each country, sector and level that mentioned each theme and the overall mean times mentioned for all respondents. The list of themes are ordered by the overall percentage scores mentioned per country. Country codes are: BD = Barbados (*n*=14), BZ = Belize (*n*=38), HD = Honduras (*n*=33), SKN = St Kitts and Nevis (*n*=25); sector codes are: CN = Conservation (*n*=34), EF = Enforcement (*n*=11), EN = Environment (*n*=17), FS = Fisheries (*n*=21), TM = Tourism (*n*=19), CM = Community* (*n*=3), RE = Research* (*n*=5), (* denotes less than ten respondents per group); and level categories are Local (*n* = 49) and National (*n* = 61). Colour scale: red-orange-yellow-light green-green denotes high to low response values in 20% quintiles. The three driver themes in grey were not included in the PCA.

Driver theme	**Overall %**	**% mentioning each theme per country**				**% mentioning each theme per sector**							**% mentioning each theme per level**	
PROXIMATE		**BD**	**BZ**	**HD**	**SKN**	**CN**	**EF**	**EN**	**FS**	**TO**	**CM**	**RE**	**Local**	**National**
Pollution	84	100	74	88	72	88	91	82	75	79	67	50	84	79
Fishing impacts (direct)	78	43	92	82	96	88	72	76	85	84	67	100	80	87
Physical damage	76	71	68	79	84	68	82	76	95	79	33	50	76	75
Bleaching, water temp' & acidification	72	79	74	73	64	82	55	82	65	63	33	83	65	77
Sedimentation & dredging	61	64	50	58	72	71	27	65	65	42	67	67	54	64
Storms & natural disasters	48	43	50	48	52	53	27	58	60	42	33	33	49	49
Algae	31	29	26	36	32	47	9	35	15	16	67	5	37	26
Coastal habitat destruction	21	0	32	30	20	47	9	18	10	16	0	33	31	20
Invasive species	20	21	16	27	16	24	9	24	25	16	0	17	27	15
Coral disease	12	21	11	12	4	15	0	18	5	0	0	50	4	16
Other ecological changes	8	14	3	9	4	3	0	12	5	5	67	0	6	7
DISTAL														
Governance structure & process	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Enforcement	96	93	95	94	100	97	100	94	90	100	67	100	96	95
Resources, capacity & funding	89	79	92	91	88	97	82	88	90	79	100	83	92	87
Management	82	79	74	85	92	88	64	88	85	74	67	83	82	82
Prioritisation	80	93	61	82	84	82	45	82	70	74	100	100	72	80
Coastal development & changes	76	79	61	82	80	88	45	88	70	58	67	67	65	80
Climate changes	71	71	74	73	64	76	45	76	75	63	67	83	65	75
Tourism	63	57	79	76	40	65	82	65	55	89	33	33	74	61
Socioeconomic issues	62	57	58	79	52	76	55	76	40	47	100	67	65	61
Agricultural changes	32	50	37	18	24	38	0	29	25	37	33	33	31	30
Non-local impacts	30	7	50	33	28	35	18	35	20	58	33	33	29	39
Fishing impacts (indirect)	22	0	37	24	28	26	45	12	45	16	0	17	27	26
Tradition & culture	22	43	3	15	28	15	9	24	20	11	0	50	16	18
Social drivers	15	7	11	3	40	12	18	18	15	21	0	0	8	20
Marine transport & industry	14	29	8	12	8	9	27	12	5	16	0	17	14	10
Markets	11	7	13	9	16	15	0	6	10	26	0	0	12	11

Table 5. Principal Components Analysis (PCA) of proximate (P) and distal (D) driver themes associated with reef health. Factor loadings of <0.3 are not displayed. Themes strongly loading onto each component (loadings >0.5) are shown in bold.

Driver theme % variance explained	PC1 10%	PC2 9%	PC3 9%	PC4 8%	PC5 7%
Coastal development & changes (D)	**0.85**				
Sedimentation & dredging (P)	**0.70**				
Management (U)	**0.58**				
Coastal habitat destruction (P)	**0.50**		-0.30		
Resources, capacity & funding (D)	0.39				
Fishing impacts (P)		**0.72**			
Socioeconomic issues (D)		**0.56**			
Marine transport & industry (D)		-0.47	0.34		
Fishing impacts (D)		0.43	0.37		
Algae (P)		0.42			
Agricultural changes (D)			**0.68**		
Climate changes (D)			**0.59**		
Pollution (P)			**0.51**		
Bleaching, water temp & acidification (P)			0.36		
Storms & natural disasters (P)				**0.74**	
Physical damage (P)				**0.70**	
Markets (D)		0.39		-0.44	
Invasive species (P)				-0.38	
Tourism (D)					**-0.65**
Prioritisation (D)					**0.51**
Tradition & culture (D)					0.48
Coral disease (P)					0.46
Non-local impacts (U)			0.32	0.31	-0.43
Enforcement (U)				-0.32	-0.33

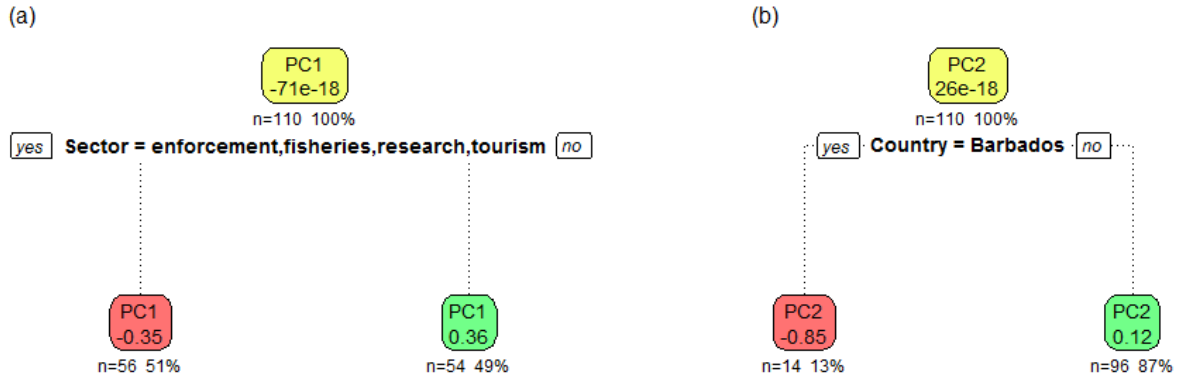

Figure 2. Classification-tree analysis evaluating country, sector and governance level as predictors of perceptions of narratives described by (a) PC1 and (b) PC2. Colours indicate direction of scores on PCs (green = high, red=low). Each node shows the predicted value and the number and percentage of respondents. Respondents meeting the split conditions pass down to the left-hand branch.

4. Discussion

This study offers unique insights to advance current understanding of threats to coral reefs by assessing how a diverse set of reef management stakeholders perceive a broad range of proximate and distal drivers of reef health in the Caribbean. Here the drivers, the potential sources of variation in responses, and the implications for the future management of coral reef resources are discussed. More generally, this study offers further support that perceptions data can be used to examine and compare issues relating to environmental drivers across multiple countries. This approach may provide insights into how broad-scale environmental perceptions can be used to help improve national or international management strategies and policies [60]. For example, by understanding variability in perceptions in relation to scientific assessment of threats, and by documenting commonalities and differences as a basis for discussions of common priorities.

4.1. Understanding the drivers of Caribbean coral reef health

A recent large-scale scientific assessment of the status of Caribbean coral reefs urgently stresses the need to better understand the drivers of ecological degradation of reefs in this region [26]. Focusing on potential anthropogenic drivers of change for the Wider Caribbean, the authors argue that all too often there is a failure in distinguishing between drivers of coral decline (e.g. overpopulation, overfishing, pollution) and their direct effects (e.g. reduced fish abundance, coral bleaching, increased macroalgae) – as drivers are often inextricably linked to one another. Indeed, the findings presented support this view, showing respondents perceived more than 100 different proximate and distal drivers affecting reefs across the region.

While Jackson et al. [26] relied on ecological data to support their conclusions, clear similarities are identified between their findings and the qualitative data reported here. Across the Caribbean the major drivers of reef degradation are categorised by Jackson et al. [26] as: population increase (residents and visitors); overfishing (e.g. including issues relating to herbivore reduction, macroalgae increase, gear types); coastal pollution (e.g. including issues relating to sedimentation, coastal development, agriculture and land clearance); ocean warming and coral bleaching; invasive species (e.g. lionfish, marine transport and ballast water issues); coral disease (e.g. invasions, water temperature and pollution); and hurricane impacts. All of these threats have been reported in reviews addressing the impacts to coral reefs [e.g. see 23, 30, 32, 61, 62].

Expert judgement and opinion have been used to assess threats to specific marine regions (e.g. the Northwestern Hawaiian Islands [63], the California Current [64]), ecosystems (e.g. 23 distinct global marine ecosystems [65], seagrass bioregions [66]) and species (e.g. sea turtles [67, 68]). However, very few studies have gathered perceptions of reef managers and policy makers specifically regarding threats to coral reefs in the Caribbean [i.e. 4, 15]. A study of coral reef researchers undertaken in 2004 found that of 39 possible threats to coral reefs identified, individuals working in the Caribbean considered common issues to be: human population, overfishing, coastal development, nutrient enrichment, algal abundance, bleaching, habitat destruction, mangrove loss, tourism, pollution, coral disease and *Diadema* dieoff [15]. Lack of education about reefs, and issues relating to laws and enforcement were also identified to negatively affect Caribbean reefs [15]. In the Caribbean UK Overseas Territories, issues relating to climate change, coastal development, pollution and overfishing were deemed by reef managers and policy makers to be the most important stressors to coral reefs [4].

Compared to responses about proximate drivers, there were more notable divergences between reporting of distal threats in the scientific literature and results presented here. Studies have

highlighted the importance of individual distal drivers that relate to some of these themes; such as market access, population density and socioeconomic development [2, 45, 69], food and human security issues, governance challenges [70], and education [30]. Specific management and governance issues have also been highlighted relating to Caribbean coral reefs [71, 72]. The qualitative approach of this study provided respondents with space to freely discuss the distal drivers of reef health, providing a more complete understanding of the complex and diverse factors associated with the management and governance of Caribbean reef ecosystems. The methodology permitted prompting about issues relating to governance and management, which inevitably influenced response rates, nevertheless results demonstrate notable consensus on perceptions of these important drivers.

This study goes beyond the current literature in articulating for the first time perceived proximate and distal drivers in a multi-country coral reef context. While significant research has been undertaken to enhance our knowledge of the biophysical dynamics and impacts affecting coral reefs, and responses from this study are consistent at this level, relatively few studies have used a holistic approach to understand the range of underlying impacts [2]. This study adds weight to growing recognition that perceptions-based data can be hugely informative for natural resources management. Integration of stakeholder knowledge and perceptions data can provide important contextual factors that may otherwise be obscured by more traditional quantitative and longitudinal monitoring methods [16]. Stakeholder participation in monitoring and evaluation can also lead to opportunities for capacity building, coproducing knowledge, and ensuring context-specific, fit-for-purpose management recommendations [60]. These data deserve a central place in the plurality of methods available when adapting contextually sensitive management programs and policies [60]. This study has taken this more holistic approach, for the first time, to canvas and assess managers and policy makers' perceptions of *both* proximate and distal threats to Caribbean coral reefs. Gathering perceptions on the relationships between proximate and distal threats can provide important context-specific data that is quicker and cheaper to collect than trying to assess a diversity of links quantitatively, and may be complementary to quantitative ecological research by generating hypotheses to test. However, individual perceptions may be influenced by a number of external factors, including interaction with peers, media, or the misinterpretation of trends, therefore triangulation of qualitative and quantitative methods remains important.

4.2. Variation in perceptions

This study hypothesised that perceptions may vary between countries on account of differences in key characteristics, such as historical marine management, reef health and resource use. Indeed, perceptions of a narrative related to fishing and socioeconomic issues (PC2) were weaker in Barbados compared to the other three countries. This highlights differences in dependency on reef fishing, market demand for reef resources and the subsequent extent of fishing activity in each country, indicating that fishing impacts on reefs are perceived to be potentially of greater concern in Belize, Honduras and St Kitts and Nevis, compared to Barbados, which is least dependent on nearshore fisheries [73].

Sectoral differences are highlighted with differences in perceptions relating to PC1, comprising perceptions of a narrative relating to reef management and coastal development. Respondents from the community, conservation and environment sectors were shown to perceive this narrative more strongly, compared to the other four sectors. Community respondents (e.g. local mayors) seeing and working at the grass-roots level may be more familiar with problems associated with poor management and impacts from coastal development. In addition, members of the conservation, environment and community sectors may be more likely to deal with a broader array of issues and

threats, compared to sectors such as fisheries and tourism that may have a narrower remit in relation to reef management.

4.3. Implications for coral reef management

The two principal components associated with varying perceptions among respondents across countries and sectors go some way to identifying distinctions in group level discourses around drivers impacting Caribbean reefs. Arguably however, one of the notable findings of this study is the overall commonality in respondents' perceptions across the four study countries, sectors and governance levels. Results empirically show that coral reef managers and policy makers across the Caribbean region are in broad agreement when it comes to the problems faced. Importantly, this includes perceptions about the distal drivers that are fundamental to effective reef management, and have to date, been less frequently documented [56]. This study may therefore present a relatively optimistic picture of shared understanding regarding the threats to Caribbean reefs - a critical factor in effective environmental management is a mutual appreciation and awareness of the issues [1].

Yet, the results also highlight a level of diversity among individual perceptions. Thus, rather than local country-specific or contextual characteristics, differences may also be attributed to personal experience, cultural norms, awareness and/or knowledge [60], which we were unable to test here. The importance of understanding where individuals gather their knowledge (e.g. primary scientific literature, personal experience) has been identified as an important factor in the success of adaptive marine management and governance [74, 75]. Indeed, it has been shown that although marine resource managers and scientists may have similar research interests and identify common priorities, managers and policy makers tend to rely less on scientific information, and more on individual experiences when developing and implementing management actions [76, 77]. This is a key consideration, because while personal experience can be linked to awareness of an issue, issues more commonly perceived may not be those of greatest ecological importance.

Indeed, additional factors may affect individual perceptions. For instance, perceptions may be influenced by social norms or taboos, which may help to explain the limited perception of fishing as a threat to reefs in Barbados, as it is uncommon in Barbados to make negative references to overfishing because of concerns for the viability of local fishers' livelihoods [78, pers. comm.]. Social and economic factors have also been shown to influence how people perceive their environment [79], while other barriers, such as social ties or fear of reprisals may prevent people from voicing their concerns [80]. Taking account of explanatory factors when distinguishing between whether an issue is widely perceived (i.e. there is high awareness) and whether it is ecologically important, can be helpful in explaining and contextualising future management options. Critically, perceptions data may be a good basis for management action [60], but effort should also be made to determine whether the majority perception is consistent with findings of quantitative ecological research.

5. Conclusions

For coupled social and ecological systems such as coral reefs, the inability to clearly identify cause-and-effect relationships between stressors and responses, relating to proximate and underlying factors, currently limits effective management [31]. By fully assessing the relationships between distal and proximate drivers and response trends, more effective targeting of coral reef management strategies can be achieved. Improved communication, collaborative approaches to research, and improved conditions for management agencies to publish, read and participate in scientific research have been

shown to lead to a shared understanding among coral reef managers and academics [76]. Future efforts should support effective communication channels and collaborative approaches to enhance a continued mutual understanding of the threats and management requirements for Caribbean coral reefs. Combined knowledge of proximate and distal drivers can offer a context for future decision-making that better reflects the concerns of local people and their natural resource managers.

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